# Coating Development for GRCop-84 Liners for Reusable Launch Vehicles Aided by Modeling Studies

The design of the next generation of reusable launch vehicles calls for using GRCop-84 copper alloy liners based on a composition invented at the NASA Glenn Research Center (ref. 1). Despite its considerable advantage over other copper alloys, it is expected that GRCop-84 will suffer from environmental degradation depending on the type of rocket fuels used and on thermomechanical fatigue (refs. 2 to 4). Applying protective coatings on GRCop-84 substrates can minimize or eliminate many of these problems and extend the operational life of the combustion liner. This could increase component reliability, shorten depot maintenance turnaround times, and lower operating costs. Therefore, Glenn is actively pursuing the development of advanced coatings technology for GRCop-84 liners. Technology is being developed in four major areas: (1) new metallic coating compositions, (2) application techniques, (3) test methods, and (4) life prediction design methodology using finite element analysis. The role of finite element analysis in guiding the coating effort is discussed in this report.
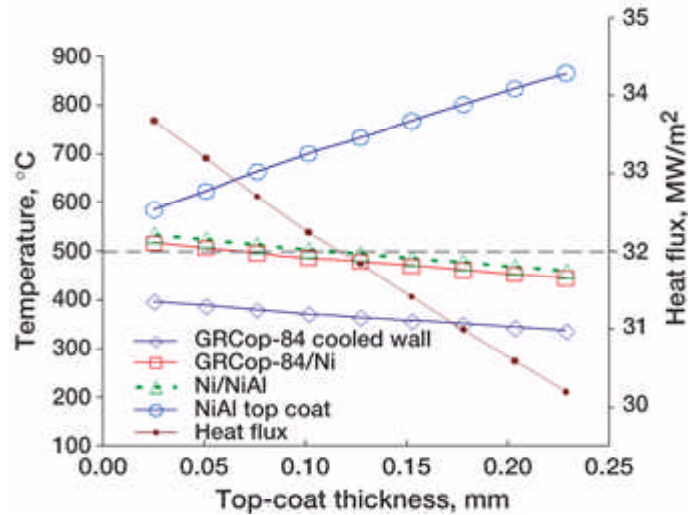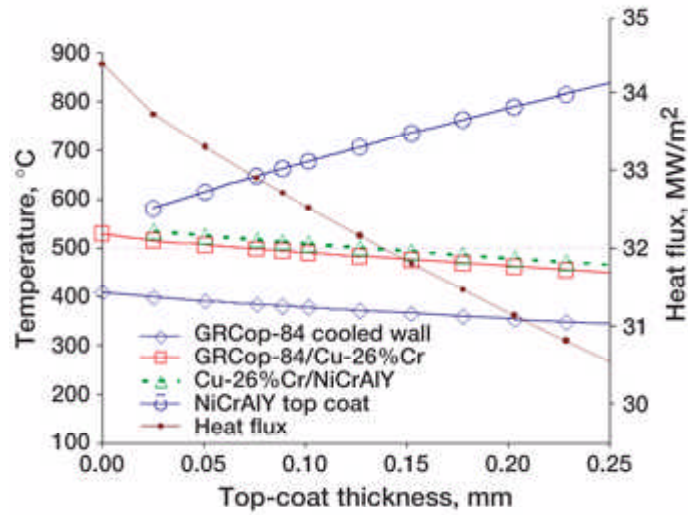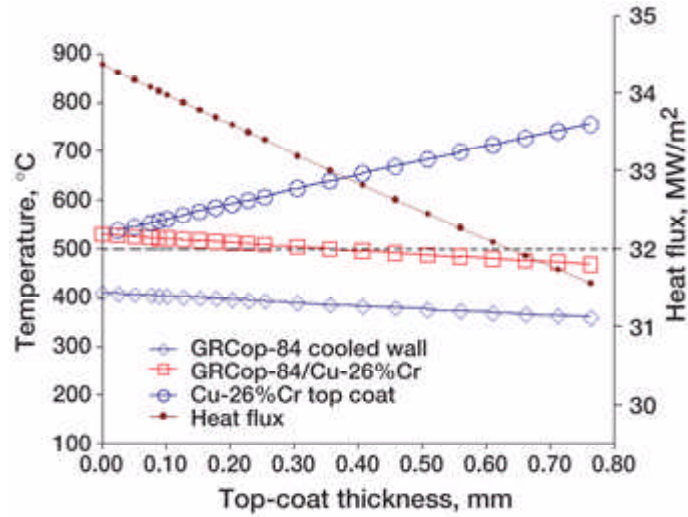
*Effect of different coatings on the expected temperature distribution of the GRCop-84 liner in a rocket engine environment for a bond-coat thickness of 50 μm. The temperature of the hot gas was assumed to be 3277 °C; the coolant temperature, -176*

Thermal analyses were performed at Glenn for different combinations of top- and bond-coat compositions to determine the temperature variation across the coated cross section with the thickness of the top coat. These calculations were conducted for simulated LH₂/LO₂ booster engine conditions assuming that the bond coat had a constant thickness of 50 µm. The preceding graphs show the predicted temperatures at the outer surface of the top coat (hot wall), at the top-coat/bond-coat interface, at the bond-coat/GRCop-84 interface, and at the GRCop-84 cold wall as a function of top-coat thickness for Cu-26(wt%)Cr top coat (top graph), Ni-17(wt%)Cr-6%Al-0.5%Y top coat and Cu-26%Cr bond coat (center graph), and NiAl top coat and Ni bond coat (bottom graph). In all cases, the temperature of the top coat at the hot wall increased with increasing top-coat thickness and with corresponding decreases in the temperatures at the two interfaces and the cold wall. These temperatures are not acutely sensitive to the thermal conductivity of the top coat when it exceeds 25 and 50 W/m/K for low and high heat flux engines (see the next set of graphs). This observation is significant for two reasons. First, several different top-coat compositions can be evaluated as potential protective coatings without loss in the heat-transfer efficiency of the coated system. Second, materials with thermal conductivities less than the critical values of 25 or 50 W/m/K are more likely to act as thermal barrier coatings.
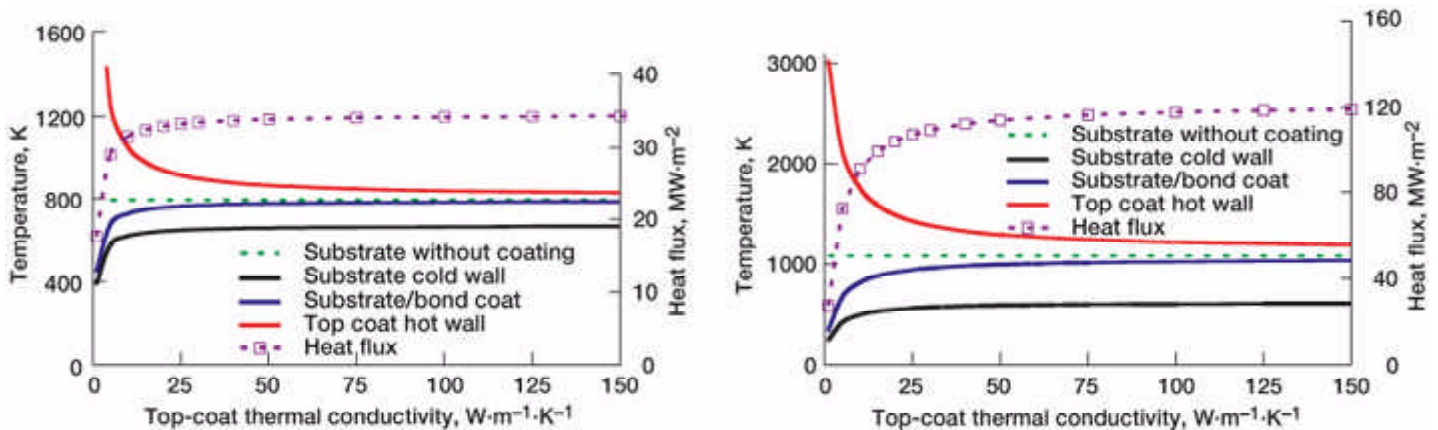


*Predicted temperature variation across the cross section of coated GRCop-84 substrates in a rocket engine environment for top coats with different thermal conductivities. The thicknesses of the bond coat, top coat, and liner were assumed to be 50 µm, 100 µm, and 1.0 mm, respectively. Left: Low-heat-flux rocket engine. Right: High-heat-flux rocket engine.*

The deposition of overlay coatings on GRCop-84 substrates results in the development of residual stresses (ref. 5). The presence of these residual stresses influences the probability of coating spallation, the thermal cycling life, and the fatigue properties of the coated substrate during use. Since it is important to understand how these stresses develop during the vacuum-plasma-spraying coating deposition process, the nature and magnitudes of the cool-down residual stresses were calculated and compared with experimentally determined

values across the coated cross section of a disk specimen. The calculations were conducted assuming that the specimen cools down to room temperature from vacuum-plasma-spraying temperatures of either 250 or 650 °C. The effects of coating the substrate with and without grit blasting were also theoretically examined. The final graph compares the predicted and the experimental results for a GRCop-84 disk coated with about a 50-µm-thick Ni bond coat and a 75- to 100-µm NiAl top coat, where the curves for NASA-2 assume the presence of a prior residual stress generated by grit blasting under conditions similar to the experimental situation. The predicted cool-down in-plane stresses were compressive in both the NiAl top coat and the Ni bond coat. They were also compressive in the substrate to a depth of about 0.25 mm from the Ni/GRCop-84 interface when the vacuum-plasma-spraying temperature was low. However, using a higher plasma spraying temperature is likely to leave the substrate under a small tensile stress to counter the compressive stresses in the bond and top coats because of the relaxation of residual stresses generated in the substrate during the grit blasting of its surface prior to spraying. These results suggest that the NiAl and Ni coatings are unlikely to spall after spraying as confirmed by the microstructural observations shown in the following photomicrograph of an as-sprayed specimen. Finally, it is noted that the calculated and experimental results are not in complete agreement, which indicates that both the experimental and modeling techniques need further refinement.
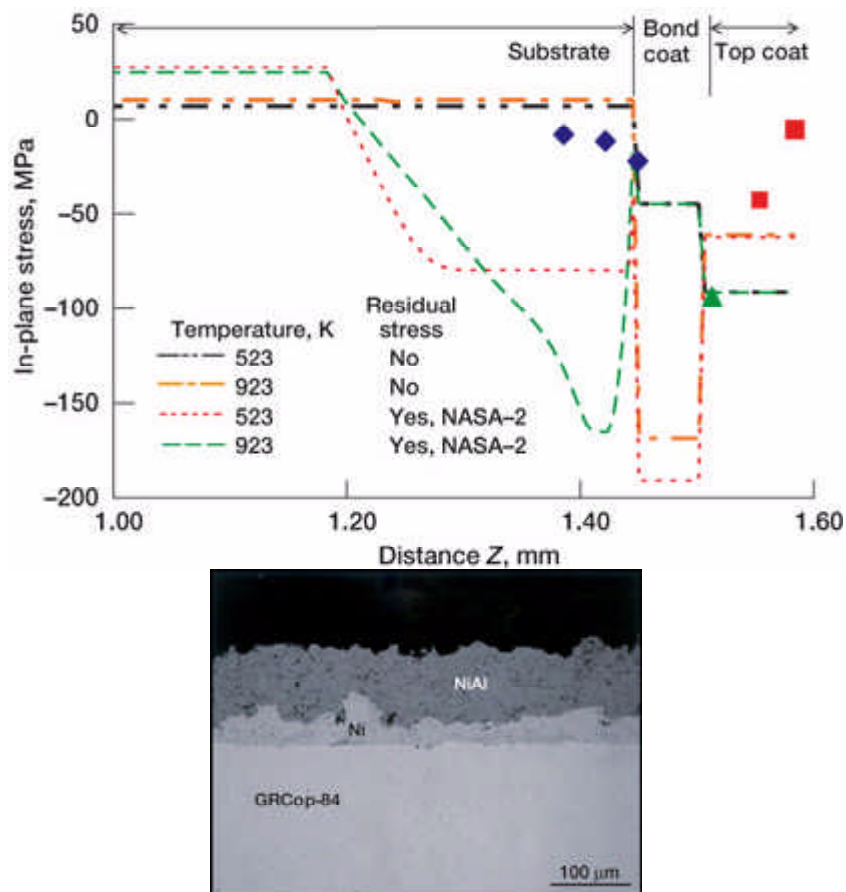


*Left: Comparison of experimental and calculated residual stresses at different points across the NiAl/Ni/GRCop-84 cross section, assuming that the initial specimen*

*temperatures soon after vacuum plasma spraying were 523 and 923 K for substrates with and without a prior residual stress history. Right: Micrograph of the cross section of an as-sprayed GRCop-84 substrate showing the microstructures of the NiAl top and the Ni bond coats, respectively.*

# References

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